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Abstract

Rock bolting has firmly used as the coal mine roof reinforcement in underground coal mine. The bolting effect of fully grouted rebar bolt is closely related to the bolt surface profile. This paper provides an experimental study to confirm that bolt rib internal length has great influence on bolting effect. Pull-out tests were conducted using rebar bolt with different rib spacings of 12, 24, 36 and 48. mm representatively from steel tube and from concrete. Results show that peak load increases 25.3% for bolt with large rib spacing. For pull out using concrete block, the increment of peak load between large and small rib spacing is not significant, but the bolt with large rib spacing has great absorption of deformational energy than small rib spacing bolt. This study provides experimental evidence towards optimum design of rock bolt for understand coal mining industry.

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Effect of bolt rib spacing on load transfer mechanism



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ABSTRACT

Rock bolting has firmly used as the coal mine roof reinforcement in underground coal mine. The bolting effect of fully grouted rebar bolt is closely related to the bolt surface profile. This paper provides an experimental study to confirm that bolt rib internal length has great influence on bolting effect. Pull-out tests were conducted using rebar bolt with different rib spacings of 12, 24, 36 and 48 mm representatively from steel tube and from concrete. Results show that peak load increases 25.3% for bolt with large rib spacing. For pull out using concrete block, the increment of peak load between large and small rib spacing is not significant, but the bolt with large rib spacing has great absorption of deformational energy than small rib spacing bolt. This study provides experimental evidence towards optimum design of rock bolt for understand coal mining industry.

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1. Introduction

The stability of underground excavations and surface slopes is of major concern to geotechnical engineers and mine operators. Rock bolting technology has firmly used as the coal mine roof primary reinforcement system in underground coal mine support design due to a better understanding of load transfer mechanisms of rock bolting and advances made in the bolt system technology [1]. In 2011, around 66% of nearly 97 million roof bolts installed in United States coal mines were fully grouted resin bolts [2].

Rock bolts used for rock formation reinforcement in mining industry is developed from ribbed steel tendon used in concrete reinforcement in building construction; however, it differs in function from the concrete beam reinforcement as the roof bolt in underground coal mine is confined by boundless surrounding rock.

A reinforcement system of rock bolt comprises five elements: the rock, the grout, the bolt and the rock/grout interface and the grout/bolt interface. Consequently, axial failure mode of grouted rock bolt system is in one or more of the manners: the bolt, the grout, the rock, the bolt-grout interface or grout-rock interface [3]. The type of axial failure depended on the properties of individual element. The steel bar is the govern element the axial behavior of the reinforce system. If the bolt had sufficient length to transfer the entire load to the surrounding rock mass it would fail. The shear stress at the bolt/grout interface was often greater than that

at the grout/rock interface because of the smaller contact area. If the grout and rock were of similar strengths, failure could occur at the bolt-grout interface. If the surrounding rock was softer, then, failure could occur at the grout/rock interface.

Studies of bolt/grout interface for rebar show that bonding forces is made up of three components: chemical adhesion, friction and mechanical interlock. The adhesive strength between the bolt-resin interface is negligible [4,5]. In addition, the adhesive strength of the bond cannot be mobilised with frictional strength during the pullout process [6]. The frictional components can be categorised into dilation slip, shear failure of surrounding medium and torsional resistance of bolt [7]. It should be noted that pressure generated by the internal reaction forces of the whole system has great influence on these two components.

The mechanical interlock component of the bond strength plays an important role in the load transfer capacity of the rock bolting system. It is created by the bolt profile configuration. The profile configuration is defined by the rib profile shape, and height, angle of wrap and spacing or distance between the ribs (Fig. 1). Among them, rib height and spacing are the most important profile parameters in term of load transfer for rebar bolt subjected to axial load.

Experimental and numerical studies have confirmed that bolt surface profile plays an important role on load transfer of fully grouted rock bolting systems [9–12]. Fabjanczyk and Tarrant investigated the load transfer mechanism in push out tests for rebar bolt with various rib heights [13]. They found that bolts with a lower profile height had smaller stiffness and concluded that the load transfer was a function of parameters such as hole diameter, resin mechanical properties, and bar surface configuration. Lin

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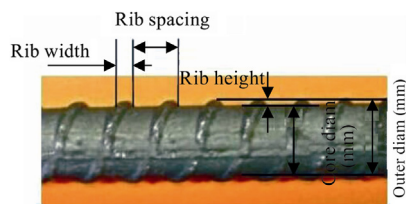


Fig. 1. Steel bolt rib profile configuration [8].

and Kang provided a review of resin anchored rebar including steel quality, profile shape, rib height and spacing in coal mine industry in China [14]. Later, an experimental study conducted by Kang et al. found that increasing rib height from 0.48 to 1.42 mm improved bolting performance of fully grouted rock bolt [15,16].

For rib spacing study, Blumel was the first to report the influence of rib spacing on load transfer capacity of the bolt [17]. Pull tests were conducted using a 500 mm length steel pipe filled in concrete. The bolt was anchored in the steel pipe using cementitious grout. Result shows that pull-out loads increase with an increase in rib spacing, of 13.7, 27.4 and 54.8 mm, respectively. Following study of the experimental findings showed that higher axial stresses were developed in case of the larger spaced ribs as compared to the small rib spacing [18]. Aziz and Webb studied profile configurations by push testing of bolts resin grouted in 75 mm cylindrical steel tubes. However, the length of steel tube was found to be of insufficient to accommodate adequate number of bolt ribs [5]. Further study indicated that increased profile spacing contributed to improvement in bolt anchorage stiffness, as indicated in Fig. 2 [19].

Previous studies provide a fundamental understanding of the role of the bolt profile and its influence on rock bolting failure. However, all tests were undertaken using steel tubes as confinement to simulate the surrounding rock mass. There has been no reported attempts made to evaluate the bolting effect for rebar bolt with different rib spacings embedded in concrete block, which can better simulate the realistic geo-conditions of underground coal mines. Accordingly, this paper presents a series of laboratory pull-out tests anchored in concrete block to evaluate bolting effect for rebar bolt with different rib spacings. In addition, pull-out tests are also conducted for bolting specimens using steel tube as confining material as a comparison to previous studies. This research work provides experimental evidence for achieving optimum bolt design in engineering applications.

2. Experiment

In order to examine the influence of increased rib spacing to bolt axial load capacity, two series of tests were carried out on bolts with different rib spacings anchored in concrete block and anchored in steel tube. For all tests, core diameter 20 mm steel bolt was used. Table 1 and Fig. 3 show a summary of the profile dimen-

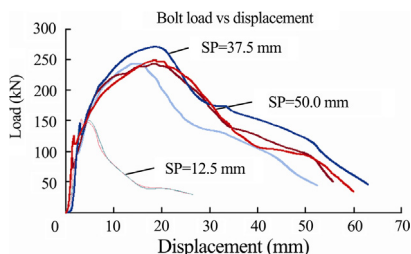


Fig. 2. Laboratory studies of steel bolt pull-out tests showing the maximum load for various spacing of the bolt profile [19].

Table 1

Parameters of tested bolts.

Item (mm)	B12	B24	B36	B48
Rib spacing	12	24	36	48
Rib height	1.8	1.8	1.8	1.8
Rib width	4.3/5.7	4.3/5.7	4.3/5.7	4.3/5.7

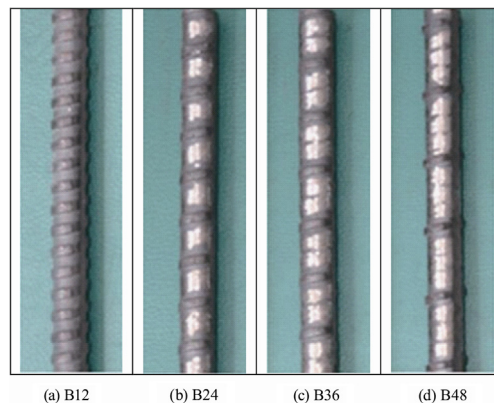


Fig. 3. Samples of tested bolts.

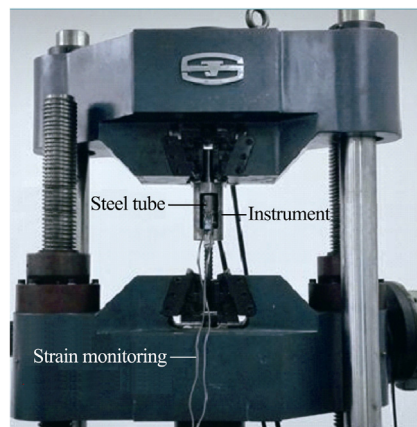


Fig. 4. Pull-out test of steel tube bolt specimen.

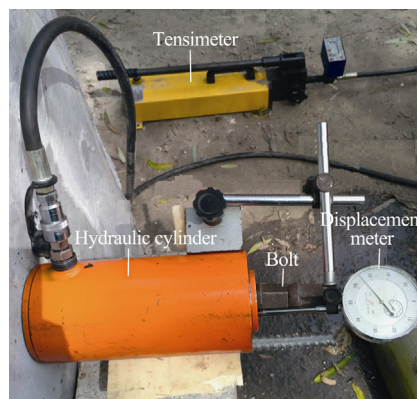


Fig. 5. Pull out test from concrete block.

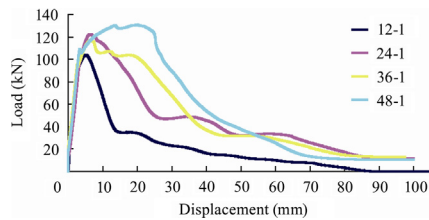


Fig. 6. Load-displacement curves for different bolt rib spacings (group 1).

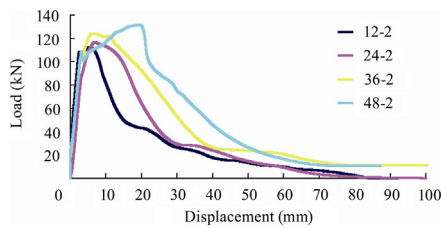


Fig. 7. Load-displacement curves for different bolt rib spacings (group 2).

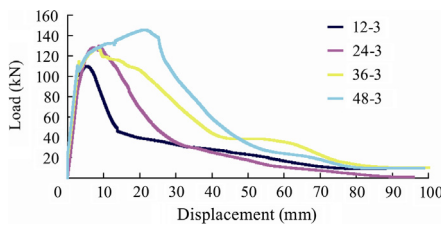


Fig. 8. Load-displacement curves for different bolt rib spacings (group 3).

sions for all the bolts that were tested. Wider profile spacings were achieved by grinding various profiles. Bolts labelled B12, B24, B36 and B48 represent rib spacings of 12, 24, 36 and 48 mm respectively. Tensile tests were conducted for original 12 mm rib spacing bolt and result showed that the yield strength of the bolt was 403.1 MPa and ultimate strength was 567.5 MPa representatively.

The encapsulation medium was a polyester Mix and Pour resin. The resin had curing time of 5–8 min. The average uniaxial compressive strength (UCS) of the resin was measured as 54 MPa after 48 h curing, the shear strength varied from 8.9 to 33.1 MPa with an average value of 22.9 MPa, modulus of elasticity of 12 GPa, and stiffness value after 2 days was around 35 kN/mm.

In preliminary tests, bolts with different rib spacings were installed into 90 mm long steel tube with internal diameter 29 mm and wall thickness of 5 mm. The steel tube was internal threaded to ensure no relative slip between the tube and the grout. Pull-out test arrangement is shown in Fig. 4, and the load and displacement were monitored on a PC, connected to a load cell and an LVDT of the loading system via a data logger.

In the second series of tests, the nominated strength of 32.5 MPa cement was used to cast concrete block at

1000 mm × 1000 mm × 1000 mm dimension. Cubic samples of the material were prepared to measure its ultimate strength of the concrete as 30.8 MPa at 28 days. After a curing period of 28 days, bolts with different rib spacings were grouted into hole drilled using 28 mm drill. The embedded length of the bolt is selected as 200 mm, which covers at least four bolt ribs. The pull-out tests were conducted using a hydraulic jacket and the displacements of the bolt were measured by an infrared displacement gauge. Fig. 5 shows the experimental arrangement of the test.

3. Results

For the first series of pull-out tests, i.e. steel tube confinement specimen, three tests were conducted for each 12, 24, 36 and 48 mm rib spacing bolt. Figs. 6–8 show three groups of load-displacement curves of the tests, each of them demonstrates the bolting effect of different rib spacings of the bolt. The result agrees well with previous studies, and demonstrates the repeatability of the tests with a reasonable degree of confidence.

Figs. 6–8 clearly demonstrate bolting effect increase with an increase in bolt rib spacing. Table 2 shows the details of the test results for the tested bolts. These results are the average values for the maximum load, shear strength, and bolt resin interface stiffness values.

The highest average peak load of 135.3 kN was that of 48 mm rib spacing. This was 25.3% greater than that achieved by the original 12 mm rib spacing bolt at 108.1 kN. The difference between these two values is attributed to the bolt rib spacings. Examination of the average displacements at peak load showed that B48 bolt achieved the highest average displacement of 20.2 mm. Bolt B24 followed this, with 8.2 mm, then followed by bolt B36 of 7.9 mm. Original bolt B12 achieved the lowest average displacement at peak with 6.0 mm. It is thus reasonable to suggest that wider profile bolts can accommodate greater peak load displacement than bolts with closely spaced profiles. This is considered as an advantage for B48 in accommodating more ground displacement without losing its load transfer capability.

For the second series of pull-out tests, i.e., pull out from concrete block, three tests were conducted for each 12, 24, 36 and 48 mm rib spacing bolts. Fig. 9 shows a typical load-displacement curves of the tests. The details of the test results are the average values for the maximum load, shear strength, and bolt resin interface stiffness values, as shown in Table 3.

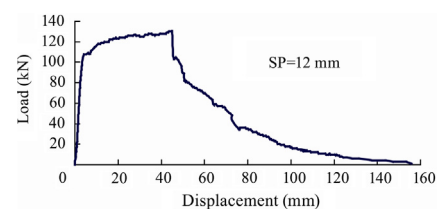


Fig. 9. Load-displacement curve of pull out of 12 mm rib spacing bolt from concrete.

Table 2
Results of steel tube pull-out.

Item	B12	B24	B36	B48
Rib spacing (mm)	12	24	36	48
Ave peak load (kN)	108.1	122.0	124.8	135.3
Ave displacement at peak (mm)	6.0	8.2	7.9	20.2
Ave shear stress (MPa)	19.1	21.6	22.1	13.9
Average bolting stiffness (kN/mm)	18.0	14.9	15.8	6.8

Table 3
Results of steel tube pull out.

Item	B12	B24	B36	B48
Rib spacing (mm)	12	24	36	48
Ave peak load (kN)	133.0	128.8	138.4	129.5
Ave displacement at peak (mm)	47.1	52.2	95.7	70.6
Ave shear stress (MPa)	10.6	10.3	11.0	10.3
Average bolting stiffness (kN/mm)	2.8	2.5	1.4	1.8

The highest average peak load of 138.4 kN was that of 36 mm rib spacing. This was 7.5% greater than that achieved by the 24 mm rib spacing bolt at 128.8 kN. However, it should be noted that the difference of the peak load for each kind of bolt is not very large. This conclusion is quite different to steel tube pull-out result in this study and also previous studies. For the axial displacement at peak, bolt with larger rib spacing is most likely has a larger displacement than shorter rib. This difference can be attributed to the bolt rib spacing. It can be concluded that, for pull-out tests from concrete block, a wider profile bolts do not improve the peak load greatly, but it absorbs more energy, that is indicated by the area under the load-displacement curve, than bolts with closely spaced profiles.

4. Conclusions

It can be concluded from this study and studies conducted in Australia and in China that, the bolting effect of fully grouted rebar bolt is closely related to the bolt surface profile, especially of rib spacing. In this study, pull-out tests were conducted using rebar bolt with different rib spacings of 12, 24, 36 and 48 mm representatively from steel tube and from concrete. Results show that peak load increases 25.3% for bolt with large rib spacing for pull-out tests using steel tube. For pull-out tests using concrete block, the increment of peak load between large and small rib spacing is not significant, however, the bolt with large rib spacing has great absorption of deformational energy than small rib spacing bolt. Results of this study confirm that the increase of the bolt rib internal length greatly improves bolting effect, and is in good agreement with previous studies. This study provide experimental evidence towards optimum design of rock bolt for understand coal mining industry.

Acknowledgments

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